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A SULFUR ISOTOPE STUDY OF MAIN-STAGE TIN AND BASE METAL MINERALIZATION AT THE EAST KEMPTVILLE TIN DEPOSIT, YARMOUTH COUNTY, NOVA SCOTIA, CANADA: EVIDENCE FOR MAGMATIC ORIGIN OF METALS AND SULFUR

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Introduction

The East Kemptville Sn-Cu-Zn-Ag deposit (initial reserves 56 million metric tons of 0.165 % Sn; 1988 production was 3,800 metric tons Sn, 305 metric tons Cu, 421 metric tons Zn, 14,836 oz Ag) is located in southwestern Nova Scotia at the southern extremity of the large (10,000-km^2), 370-Ma, peraluminous, S-type South Mountain batholith (see Clarke and Muecke (1985) and references therein; Figs. 1 and 2). Mineralization is confined to topaz-rich greisen and vein systems in a muscovite-topaz leucogranite which has petrologic affinities to topaz rhyolites or ongonites (Kontak, 1987a, b). The regional and local geology of this world-class stanniferous deposit, including geochemistry, vein mineralogy, isotopic data, and fluid inclusion studies, have been discussed by Richardson et al. (1982), Richardson (1983, 1988a, b), Kontak (1987a, b, 1988), and Kontak et al. (1988). In this communication the results of a sulfur isotope study of the tin and base metal stages of mineralization are reported and discussed in context with other sulfur isotope data for mineralization in the Meguma terrane of Nova Scotia (Fig. 1) and recent determinations for other important centers of lithophile metal mineralization (e.g., Panasqueira, Kelly and Rye (1979); Renison Bell, Patterson et al. (1981); and San Cristobal, Campbell (1987)).

Although it is generally inferred that metals and fluids involved in lithophile metal mineralization share a magmatic derivation (Taylor, 1979; Strong, 1981, 1988), some recent data (e.g., Shepherd et al., 1977; Norman and Landis, 1983; Campbell, 1987; Shelton et al., 1987) indicate that external reservoirs may be involved in, or even promote, the processes responsible for metal precipitation (see Strong, 1988, for review). In addition, both Sheppard (1977) and Ohmoto (1986) have shown that at some stage in the paragenesis of hydrothermal vein deposits of magmatic affiliation, incursion of meteoric water occurs. Thus it is not surprising that Richardson (1988a), Richardson and Blenkinsop (1989), and Richardson et al. (in press) have documented the presence of highly variable strontium isotope signatures for phosphate and fluorite mineralization at East Kemptville, which indicated to Richardson et al. (in press) that a nonmagmatic component(s) was involved in late hypogene stages of mineralization. The sulfur isotope data presented herein permit, therefore, a further evaluation of the sources involved for the metals and sulfur, and by extrapolation the fluids, in the genesis of the East Kemptville deposit.

Regional and Local Geologic Setting and Age of Mineralization

The Kemptville deposit occurs at the southwest margin of the large, 370-Ma (Clarke and Halliday, 1980; Reynolds et al., 1981) South Mountain batholith (Fig. 1), previously considered to be favorable for stanniferous mineralization (Smith and Turek, 1976). The batholith intrudes lower Paleozoic metaturbiditic sedimentary rocks of the Meguma Group which were deformed during the mid-Devonian Acadian orogeny. This deformational event records the accretion of the Meguma terrane (area south of the Cobequid-Chedabucto fault system in Fig. 1) to the Maritime segment of the Appalachian collage (Keppie, 1982).

Recent mapping of the South Mountain batholith by the Nova Scotia Department of Mines and Energy staff (summarized in MacDonald et al., 1988) has demonstrated its composite nature with the recognition of several discrete intrusive centers. Of importance here is the most westerly intrusive center, referred to as the Davis Lake Complex (Fig. 2). Whereas the predominant lithologies of the Davis Lake Complex are biotite monzogranite, muscovite-biotite monzogranite, and coarse-grained leucomonzogranite, in at least two areas muscovite-topaz leucogranites occur (Fig. 2). The East Kemptville deposit is hosted by one of these topaz granites, occurring as a small lobe off the batholith proper. This topaz granite intrudes (?) the South Mountain batholith on one side and metasedimentary rocks of the Meguma Group on the opposite side.

Initial studies by Richardson (1983) and Richardson et al. (1982) described the deposit as a large greisen zone peripheral to variably altered granites (sensu lato) of the South Mountain batholith. However, more recently Kontak et al. (1986), based on mapping of the northern part of the orebody, have shown that mineralization is hosted by a medium-grained, equigranular, muscovite-topaz leucogranite. This granite lithology exhibits a uniform mineralogy and chemistry within the deposit area and it is estimated to underlie approximately 40 percent of the mine. Furthermore, Kontak (1987a, b, 1988) has argued that the unusual mineralogic and geochemical features of this unit re-

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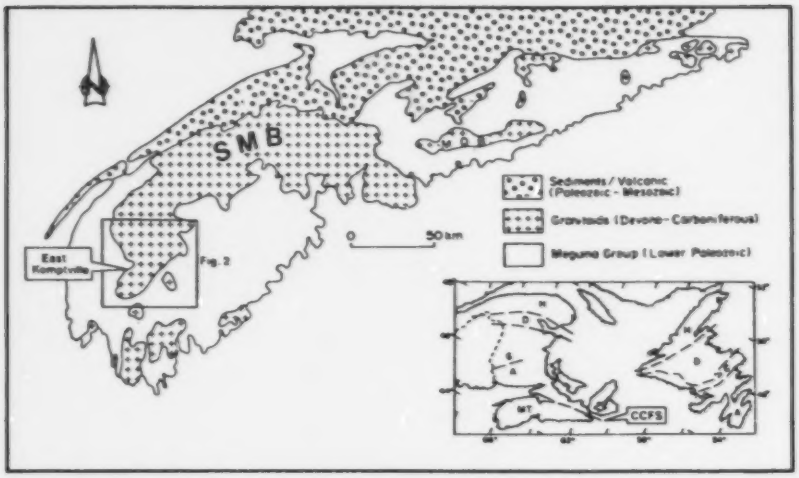

FIG. 1. Simplified geologic map of southern Nova Scotia showing the major lithologic units of the Meguma terrane. Location of the Meguma terrane (MT) and its bounding fault (Cobequid-Chedabucto fault system, CCFS) in the Maritime Appalachians is shown in the inset figure. Other terranes indicated in the figure are the Avalon (A), Dunnage (D), Gander (G), and Humber (H). The large South Mountain batholith is shown as SMB.

quire an origin somewhat different from the rest of the South Mountain batholith, rather than appealing to extreme fractional crystallization of the Davis Lake Complex (Richardson, 1983, 1988a).

Although Zentilli and Reynolds (1985) and Richardson et al. (1988) suggested ages of ca. 300 and 330 Ma, respectively, for the mineralization, the presence of pervasive deformational fabrics within the leucogranite indicates that the isotopic systematics (^{40}Ar-^{39}Ar and Rb-Sr, respectively) may have been disturbed. In addition, O'Reilly (1988) has shown that East Kemptville is but one of several mineralized centers that lie within a northeast-trending shear zone (see Fig. 2), while Dallmeyer and Keppie (1987), Reynolds et al. (1987), and Muecke et al. (1988) have dated (^{40}Ar-^{39}Ar method) multiple episodes of thermal disturbance in this part of the Meguma terrane. Thus, the above-mentioned dates are currently interpreted as providing only minimum time constraints on the age of mineralization and intrusion.

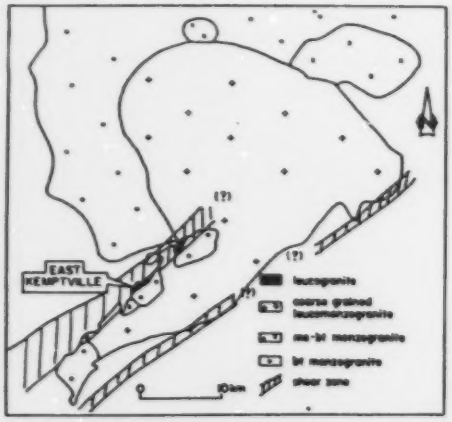

FIG. 2. Geologic map of part of southwest Nova Scotia showing the location of the East Kemptville tin-base metal deposit and simplified internal geology of the Davis Lake Complex of the South Mountain batholith (modified from MacDonald et al., 1988, with additional information from L. J. Ham and M. A. MacDonald, pers. commun., 1989).

Mineralization at East Kemptville

Mineralization at East Kemptville is dominated by cassiterite and sulfides; the paragenetic scheme is summarized in Figure 3. The salient aspects of the different mineralizing stages are presented below.

Tin at East Kemptville, in the form of cassiterite, occurs both as greisen- or vein-style mineralization. The greisens occur as either 1- to 2-m-wide, northeast-trending, zoned veins or greisens with cassiterite-rich cores mantled by successive zones dominated by topaz and quartz + sulfides ± topaz, or dark, topaz + sulfide + graphite greisens of 10- to 20-m width which contain disseminated cassiterite. Whereas the first style of mineralization may occur throughout the deposit, the latter is preferentially located at granite-sedimentary rock contacts. Vein-style mineralization, much less common compared with the greisens, consists of quartz + cassiterite ± sulfides.

Sulfide mineralization, dominated by Fe-, Cu-, and Zn-bearing phases, occurs in the greisen zones or sulfide-rich (tin-poor) veins lacking alteration selvages.

MINERALIZATION STAGES

	(1) GREISEN	(2) SULPHIDE	(3) PHOSPHATE - ALBITE	(4) CLAY	(5) ZEOLITE
quartz	x	x	x		
mica	x				
topaz	x	tr			
cassiterite	x	x			
wolframite	tr	x			
molybdenite		x			
arsenopyrite		x			
pyrite	x	x	x	tr	tr
pyrrhotite		x	x		
marcasite		x			
chalcopyrite	tr	x	tr		
sphalerite	tr	x	x	tr	
galena		x			
fluorite	tr	x	x	tr	x
albite			x		
triplite			x		
carbonates			tr	tr	tr
apatite			x		
vivianite			tr	tr	tr
clay				x	tr
zeolite					x

FIG. 3. Idealized paragenetic scheme for main stages of mineralization at East Kemptville (the x indicates that the mineral phase occurs in significant quantities, while tr signifies only trace amounts). Note that the paragenesis is complex and several minerals (e.g., beryl, columbite, uraninite, kellyite, and mcauslanite) are excluded because of their very trace abundance; in addition the different carbonates and clays have been grouped under a single heading for simplification purposes. A more detailed discussion of the paragenetic sequence is found in Richardson (1988b).

Paragenetically this mineralization stage is later than the majority of tin deposition and is succeeded by a phosphate-albite stage in which sulfides are volumetrically minor to absent. The latest stages of mineralization are represented by a clay (dickite) overprint and late crustification and fracture infillings of phosphate, carbonate, zeolite, and sulfide phases.

Although a far more detailed paragenesis has been provided by Richardson (1983, 1988b), herein the somewhat simplified stages described above are retained, viz. (1) greisen, (2) sulfides, (3) phosphate-albite, (4) clay, and (5) zeolite.

Sampling and Analytical Techniques

Sulfides were obtained from well-characterized sulfide-bearing specimens collected from the East Kemptville deposit during the period 1986 to 1987 while mining was confined to the 106-, 94-, and 82-m levels. In all samples mineralization was sufficiently coarse grained to permit easy separation by crushing to 0.5 to 1.0-mm grain size and handpicking; final separates were checked using a binocular microscope. Polished sections of the samples used indicate contained impurities to be insignificant and hence not a potential problem for isotopic analyses. In total 31 sulfide samples were separated (14 pyrite, 3 pyrrhotite, 7 sphalerite, 3 chalcopyrite, 3 arsenopyrite, and 1 galena) which represent the first three stages of sulfide-bearing mineralization. Sulfide mineralization is absent or occurs only in trace amounts in stage 4 and the results for stage 5 will be reported in a separate communication.

Sulfur isotope measurements were performed in the Department of Physics at McMaster University, Hamilton, Ontario, using the following analytical procedure. Samples were ground to −200 mesh and then thoroughly mixed with copper oxide in a ratio dependent on the composition of the mineral phase. The mixture was then oxidized in a furnace at 1,200°C and the SO_2 produced was subsequently purified on the extraction line and analyzed using a 6-inch-radius magnetic sector mass spectrometer. The $\delta^{34}S$ values are quoted relative to the Canyon Diablo troilite standard. Analyses are considered to be accurate to ±0.4 per mil (1 sigma), and several pyrite duplicates analyzed over the course of this study indicate precision is consistently ±0.1 to 0.2 per mil.

Results

Sulfur isotope compositions for 31 sulfides, their vein stage, mineral assemblage, and additional pertinent information are provided in Table 1 and displayed graphically in Figure 4. Collectively, the data show a very restricted range in $\delta^{34}S$ values from 3.6 to 6.6 per mil. Grouped according to respective mineral phases, the averages ($\pm 1\sigma$) for the sulfides are as follows (‰): pyrite = 5.1 ± 0.2 (n = 14), pyrrhotite = 5.5 ± 0.1 (n = 3), sphalerite = 5.4 ± 0.3 (n = 7), chalcopyrite = 4.9 ± 0.4 (n = 3), arsenopyrite = 6.5 ± 0.0 (n = 3) and galena = 3.6 (n = 1). A pyrite-pyrrhotite mixture from stage 2 mineralization was analyzed in duplicate and similar results of 5.2 and 5.4 per mil were obtained.

Sufficient data (n = 14) exist for pyrite from different stages (1, 2, 3) to examine the possibility of temporal variations in $\delta^{34}S$ during hypogene mineralization. The results according to mineralization stages are as follows (‰): stage 1 = 4.8 ± 0.2 (n = 3), stage 2 = 5.1 ± 0.2 (n = 8), and stage 3 = 5.2 ± 0.1 (n = 3). The present data set indicates, therefore, a uniform value for pyrite during the main mineralizing stages.

Discussion

Sulfur isotope composition of ore fluid and source of S at East Kemptville

The sulfur isotope composition of sulfur-bearing phases has been shown to be sensitive to the physiochemical (i.e., T, Eh, pH) conditions of the ore fluid (e.g., Ohmoto, 1972; Rye and Ohmoto, 1974). Thus, small variations in any one of these intensive parameters could influence the $\delta^{34}S$ values of the precipitating S phase if the ore fluid had an intermediate H_2S/SO_4 ratio (see figs. 10.8 and 10.9 in Ohmoto and Rye, 1979). Conversely, a restricted range in $\delta^{34}S$

TABLE 1. Sulfur Isotope Data and Descriptions of Sulfide Samples, East Kemptville

Sample no.	Mineral analyzed	Stage[1]	Vein assemblage[2]	$\delta^{34}S$ (‰)[3]	Comments
EK-86-019	Sphalerite	2	Qtz-sph-py-cpy	5.1	Coarse qtz-sph with fine-grained cpy-py; vein cuts fresh granite
EK-86-038	Arsenopyrite	2	Aspy-py-po-cpy	6.5	Coarse aspy + sulfide in altered granite; clay overprint
EK-86-041	Arsenopyrite	2	Aspy-py	6.6	Deformed aspy-rich vein in sericitized granite
EK-86-055	Pyrite	2	Qtz-py-sph-cpy	5.3	Vein in gray granite containing disseminated py
	Sphalerite		Qtz-py-sph-cpy	5.3	
EK-86-066	Sphalerite	2	Qtz-py-sph-cpy-po	5.5	Coarse, euhedral vein mineralogy; clay overprint, vein cuts sericitized granite
	Galena		Qtz-py-sph-cpy-po	3.6	
	Chalcopyrite		Qtz-py-sph-cpy-po	5.2	
EK-86-076A	Pyrite	1	Qtz-top-cass-py-cpy-sph-po	5.1	Zoned cass-top greisen; sulfide late stage
EK-86-096	Sphalerite	2	Qtz-sph-py	5.5	Qtz sulfide vein in fresh granite; late clay overprint
EK-86-110	Chalcopyrite	3	Qtz-tlp-cpy-py-viv	4.3	Qtz sulfide vein cutting fresh granite; vivianite late stage
	Pyrite	3	Qtz-tlp-cpy-py-viv	5.3	
	Pyrite		Qtz-tlp-cpy-py-viv	5.1	
EK-86-112	Pyrite	2	Qtz-py	4.7	Coarse, euhedral py; vein cuts fresh granite
EK-86-122A	Pyrite	2	Qtz-py-sph-cpy	5.2	Coarse vein mineralogy; vein cuts sericitized granite with disseminated py
EK-86-151	Sphalerite	3	Qtz-sph-py-tlp-viv	5.1	Coarse, euhedral sulfide; vivianite late
	Pyrite			5.3	
EK-86-155	Pyrite	2	Qtz-py-po-sph-cpy	5.0	Qtz-sulfide vein in top greisen; late clay overprint
	Sphalerite			5.2	
	Chalcopyrite			5.3	
EK-86-165	Pyrite	2	Qtz-cpy-py	5.3	Coarse qtz-sulfide mineralogy, vein cuts sheared, gray granite
EK-86-166	Sphalerite	2	Qtz-sph-py-cpy	6.1	Fine-grained sulfide mineralogy
EK-86-178	Pyrite	2	Qtz-py-po-sph-cpy-wolf-cass	5.5	Coarse wolf crystals in sulfide rich vein
	Pyrite			5.2	
	Pyrrhotite			5.6	
	Pyrrhotite			5.6	
EK-86-179	Pyrite/pyrrhotite	2	Aspy-py-po-cpy	5.2, 5.4	Massive aspy vein cut by fractures filled in with py-cpy-po; late clay overprint
	Arsenopyrite			6.5	
EK-87-8	Pyrite	1	Qtz-top-cass-py-cpy	4.8	Zoned top greisen
EK-87-13	Pyrite	1	Qtz-cass-py	4.6	Coarse, cassiterite-rich vein

[1] Vein stages are discussed in the text

[2] Abbreviations: aspy = arsenopyrite, cass = cassiterite, cpy = chalcopyrite, po = pyrrhotite, py = pyrite, qtz = quartz, sph = sphalerite, tlp = triplite, top = topaz, viv = vivianite, wolf = wolframite. Vein minerals given in decreasing modal percent; [3]all isotopic values are + relative to Canyon Diablo troilite standard which is taken as $\delta^{34}S = 0$

values of sulfide phases, as observed at East Kemptville, indicates that changes in such parameters were either short-lived or minimal and consequently had little if any effect on fractionation of sulfur isotopes within the fluids.

The lack of buffering assemblages (e.g., quartz-muscovite-K feldspar; pyrite-pyrrhotite-magnetite) in the veins and greisens indicates that both pH and f_{O_2} were susceptible to change. Fluid inclusion studies (Kontak, 1988, and unpub. data) indicate that the

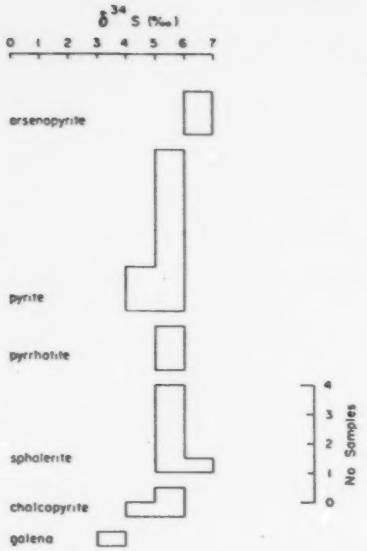

FIG. 4. Histogram of sulfur isotope data for sulfide phases at East Kemptville.

temperature of the ore fluid decreased systematically from ≥450° to 250°C during stages 1, 2 and 3. Variable temperature yet constant $\delta^{34}S$ values are interpreted to indicate that sulfur in the ore fluid was dominated by H_2S, consistent with sulfide assemblages (pyrite, pyrrhotite, and chalcopyrite), the presence of graphite in the greisens, and minor (<2 mole %) $CO_2 \pm CH_4$ in fluid inclusions. The restricted range of observed $\delta^{34}S$ values is, therefore, mainly a reflection of the nature of the ore fluid (i.e., dominated by H_2S) which inhibited fractionation of sulfur isotopes. Additional implications derived from the data set are that a homogeneous source of sulfur was available and that the fluid system remained open (i.e., fractionation did not occur because of a change in the H_2S/SO_4 ratio of the ore fluid).

The values of $\delta^{34}S_{H_2S}$ have been calculated combining the temperatures obtained from fluid inclusion thermometry and the data in Table 1; results are illustrated in Figure 5. The range in measured $\delta^{34}S_{mineral}$, as for example in galena, is seen to be a function of its fractionation factor ($\alpha_{i\text{-}H_2S}$; Ohmoto and Rye, 1979) and temperature of crystallization. However, the more important feature of this diagram is that it illustrates that all the sulfide phases originated from a common, H_2S-dominant fluid characterized by a $\delta^{34}S$ value of 5.0 ± 0.5 per mil, assuming the fluids cooled from higher temperatures (i.e., ≥500°C). Such a value is consistent with a magmatic origin for the sulfur (Ohmoto and Rye, 1979), either via late-stage fluids generated from a granitic melt or leaching of sulfur from earlier formed sulfide phases. Oxygen isotope data (Kontak, 1988, and unpub. data) for vein silicates are also compatible with this scenario.

Sulfur isotope geothermometry

In order to provide constraints on a complementary fluid inclusion study of the mineralized veins and greisens and to examine the extent of sulfide equilibria, coexisting sulfides were analyzed for five samples (see Table 1).

The samples used for geothermometry all contain coarse, subhedral intergrowths of sulfide phases in veins representing a single paragenetic stage of mineralization. Examination of the samples in reflected light microscopy indicate equilibrium assemblages from neutral grain boundaries. In light of these observations it is perhaps surprising to note that most of the assemblages record obvious disequilibrium conditions based on their $\delta^{34}S$ values, as summarized below.

For the six mineral pairs analyzed, three show reverse fractionation (i.e., disequilibrium) whereas the remainder indicate crystallization temperatures (calculated using the equations provided in Ohmoto and Rye, 1979) of 956° ± 85°C (pyrite-sphalerite, sample 151), 433° ± 75°C (pyrite-chalcopyrite, sample 110) and 344° ± 45°C (sphalerite-galena, sample 66). Sample 66 is the only one to give a temperature consistent with homogenization temperatures obtained

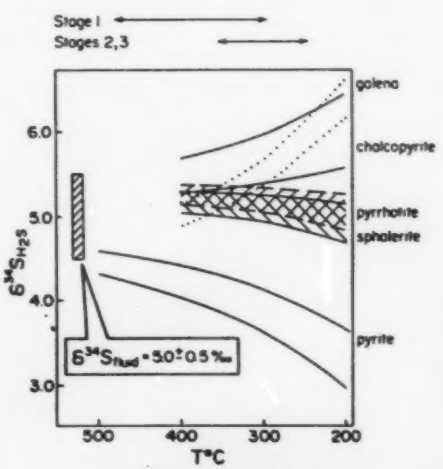

FIG. 5. Temperature vs. $\delta^{34}S_{H_2S}$ value diagram for East Kemptville sulfide phases. Diagram was constructed using the mean sulfur isotope values for each mineral (Table 1) and equations in Ohmoto and Rye (1979). The range of $\delta^{34}S_{H_2S}$ values for a given temperature for each sulfide phase incorporates the errors for the fractionation factors (H_2S mineral) given in Ohmoto and Rye (1979). The temperature ranges for the stages of mineralization are from fluid inclusion studies (Kontak, 1988, and unpub. data). The value of $\delta^{34}S_{fluid}$ was selected at 500°C since fractionation above this temperature is minimal and it represents the highest probable temperature of vein and greisen formation.

from fluid inclusions hosted by quartz in the same specimen. This is consistent with the observations of Rye (1974) and Ohmoto and Rye (1979) that this mineral pair consistently approaches equilibrium and gives fractionation values appropriate for temperatures determined independently from fluid inclusion studies.

Comparison with sulfur isotope data for Meguma terrane mineralization and potential source reservoirs

Comparison of sulfur isotope data for East Kemptville mineralization and data for other mineralized centers in the Meguma terrane, both base metal- and precious metal-bearing, is shown in Figure 6. The East Kemptville data compare most favorably with base metal mineralization, including lithophile elements (Sn, W), from within the southwestern part of the South Mountain batholith (i.e., intrabatholithic). For mineralization (either base or precious metal) hosted by the Meguma Group metasedimentary rocks (i.e., peribatholithic) $\delta^{34}S$ values are all higher than those reported for East Kemptville. Collectively, the present data set indicates, therefore, a negligible contribution of heavy sulfur from the Meguma Group. This conclusion contrasts with recent findings of Richardson and Blenkinsop (1989) and Richardson et al. (in press) who suggest that high and variable initial strontium isotope values for late-stage vein minerals (fluorite, triplite, and apatite) are a consequence of interaction of the ore fluid with Meguma Group sedimentary rocks. An important extension of this conclusion is that at least some convective flow or incursion of extraneous fluid is inferred; however, no manifestation of this process in the vicinity of the deposit has been documented. A contrasting example is provided by Morgan and London (1987) who document extensive metasomatism (B, Li, F, Rb, Cs, and K) of country-rock amphibolites which envelop the Tanco pegmatite, Manitoba. Uniformly low oxygen isotope values of vein quartz from both sulfide and phosphate-albite stages of mineralization (avg $\delta^{18}O$ value = 10.7 ± 0.6‰, (n = 14); Kontak, 1988) also favor a magmatic fluid (e.g., compare to quartz from auriferous veins in Meguma Group rocks which have $\delta^{18}O$ = 13 to 14 per mil; Kontak et al., 1988). However, it is noted that results of S, O, H, C, and Sr isotope studies at the Pasto Bueno tungsten-base metal deposit in Peru show that whereas the S isotope values remain constant at 0 ± 3 per mil, incursions of nonmagmatic components are reflected in the other isotopic data (Landis and Rye, 1974; Norman and Landis, 1983). Also, the uniform sulfur isotope values of 2 ± 1 per mil reported for the Chojlla tin-tungsten deposit by Harwood (1985) apparently indicate little influence of the wall-rock argillites which host most of the mineralization. Thus, it is possible that while strontium isotope analyses reflect the presence of a nonmagmatic component at East Kemptville, sulfur isotopes retain essentially a magmatic signature.

Also shown in Figure 6 are isotopic data for the main lithologic units in the Meguma terrane, namely South Mountain batholith and Meguma Group rocks. The scatter of the data renders it impossible to draw unequivocal conclusions; however, a sulfur source of appropriate isotopic composition is clearly available in the granitoids of the South Mountain batholith. It is also noteworthy to draw attention to the large

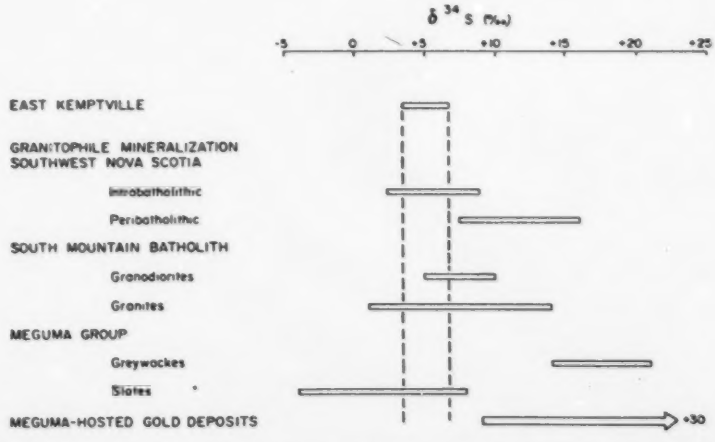

FIG. 6. Range of $\delta^{34}S$ values for East Kemptville mineralization (this study) compared with other styles of mineralization in the Meguma terrane and potential source reservoirs. Sources of data are as follows: granophile mineralization from A. K. Chatterjee (pers. commun., 1989), Meguma gold deposits from Kontak and Smith (1989) and Sangster (1987), South Mountain batholith and Meguma Group from Kubilius (1983).

spread in the data for the granitic samples. This variation has been interpreted by Kubilius (1983) to reflect the susceptibility of this low sulfur-bearing unit to contamination during emplacement into the Meguma Group. Again, as noted above, there seems to be little evidence for similar processes having modified the sulfur isotope signatures at East Kemptville.

Comparison with Sulfur Isotope Data from Other Lithophile Metal Deposits

Data for East Kemptville are compared with a compilation of S isotopes from other significant centers of lithophile element mineralization of variable styles (e.g., skarn vs. vein) and ages in Figure 7. Two features are immediately apparent, namely the relatively small range of values for East Kemptville and the comparative enrichment in ^{34}S. Despite the range in the mean $\delta^{34}S$ values for sulfides from the deposits in Figure 7, in all cases a magmatic source is favored for the sulfur, albeit with minor contamination in some cases (e.g., San Cristobal, Peru; Campbell, 1987). This variation in $\delta^{34}S_{minerals}$ value is most certainly a reflection of differences in the $\delta^{34}S_{H_2S}$ value of the fluid and therefore indicates original variations in the isotopic composition of S in the melts and source regions (e.g., Shelton et al., 1986). For example, the $\delta^{34}S$ values for different S-type granite suites (data in Ohmoto, 1986) from Nova Scotia (generally 0–15‰), Japan (−1 to −10‰), and Australia (>5‰) can be rationalized by inferring differences in the H_2S/SO_4 ratios of the source regions and variable f_{O_2} conditions during melt generation. Thus, despite the relatively enriched $\delta^{34}S$ value for sulfides at East Kemptville and therefore presumably the source region, this does not negate a magmatic origin for the S or obviate the need for contamination.

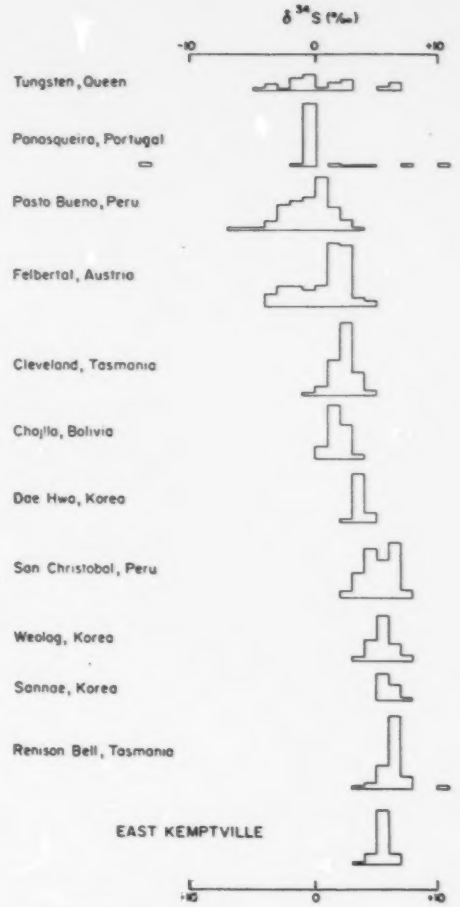

FIG. 7. Compilation of $\delta^{34}S$ data for a variety of important tin and tungsten ± base metal deposits. Sources of data are as follows: Chojlla, Bolivia (Harwood, 1985); Cleveland, Tasmania (Collins, 1981); Dae Hwa, Korea (Shelton et al., 1987; So et al., 1983b); Felbertal, Austria (Holl et al., 1987); Panasqueira, Portugal (Kelly and Rye, 1979); Pasto Bueno, Peru (Landis and Rye, 1974); Renison Bell, Tasmania (Patterson et al., 1981); San Cristobal, Peru (Campbell, 1987); Sannae, Korea (Shelton et al., 1986); Tungsten Queen, North Carolina (Casadevall and Rye, 1980); Weolag, Korea (So et al., 1983a).

Conclusions

A sulfur isotope study of sulfide phases from the tin and base metal stages of mineralization at the East Kemptville tin-base metal deposit indicates these features:

1. The range of $\delta^{34}S$ isotope values for 31 sulfides analyzed is small with minimum and maximum values of 3.6 and 6.6 per mil.
2. The $\delta^{34}S$ values (‰) for individual sulfide phases are pyrite = 5.1 ± 0.2 (n = 14), pyrrhotite = 5.5 ± 0.1 (n = 3), sphalerite = 5.4 ± 0.3 (n = 7), chalcopyrite = 4.9 ± 0.4 (n = 3), arsenopyrite = 6.5 ± 0.0 (n = 3), and galena = 3.6 (n = 1).
3. There is no systematic variation of $\delta^{34}S_{minerals}$ values for the first 3 stages of mineralization. For example, $\delta^{34}S$ values of pyrite from the tin, sulfide, and phosphate stages of mineralization are similar at 4.8 ± 0.2, 5.1 ± 0.2, and 5.2 ± 0.1 per mil, respectively. These data indicate an homogeneous source for the S, absence of fractionation during mineralization, and an open system throughout vein formation.
4. The $\delta^{34}S_{mineral}$ values are interpreted to indicate that the dominant form of S in the ore fluid was H_2S. Calculations of $\delta^{34}S_{fluid}$ values using mineral-H_2S fractionation factors and temperatures derived from fluid inclusion studies indicate a primary $\delta^{34}S_{fluid}$ value of 5.0 ± 0.5 per mil, consistent with a magmatic source for the S.
5. Consistent values of $\delta^{34}S$ for sulfides from the main stages of mineralization indicate that incursions of extraneous S were either nonexistent or minimal. This is consistent with O isotope data (Kontak, 1988)

but contrasts with the Sr isotope results of Richardson and Blenkinsop (1989) and Richardson et al. (in press), which indicate that multiple fluids may have been involved in vein formation.

6. Comparison to known high-^{34}S reservoirs in the Meguma terrane is consistent with a dominantly magmatic source of the S since interaction with Meguma Group sedimentary rocks is known to shift $\delta^{34}S$ values to more positive values (e.g., peribatholithic mineralization and Meguma gold deposits).

7. The $\delta^{34}S$ values for sulfides from East Kemptville are characterized by their narrow range and enrichment in heavy S compared with many of the more significant centers of Sn and W mineralization. These features reflect a homogeneous source of S which was itself enriched in ^{34}S compared with source regions for S in, for example, the Pansqueira, Pasto Bueno, and Chojlla deposits.

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